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EXPERIMENTAL CALCULATION OF THE RECURRENCE OF TEMPERATURE AND WIND VELOCITY COMBINATIONS IN THE LOWER 100-M LAYER OF THE ATMOSPHERE

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EXPERIMENTAL CALCULATION OF THE RECURRENCE OF TEMPERATURE AND WIND VELOCITY COMBINATIONS IN THE LOWER 100-M LAYER OF THE ATMOSPHERE

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Approximate computations of the frequency of occurrence of a combination of temperature and wind velocity at heights of 50 and 100 m are given on the basis of surface data.

Study of the lower part of the boundary layer of the atmosphere is of great interest for solving a number of problems of theoretical and applied character. /62*

There has been a particularly strong increase of interest in study of the vertical distribution of temperature and wind velocity in the lower layers of the atmosphere in relation to the design and operation of different high structures and investigation of air contamination conditions.

The lower layer of the atmosphere is formed under the influence of the underlying surface and the processes occurring in the free atmosphere. The underlying surface exerts a thermal and dynamic effect on the structure of the lower layer of the atmosphere. The thermal effect is regulated for the most part by the influx of radiant energy at the active surface and the dynamic effect is associated with the adhesion of the lower layer of the airflow to the soil surface. The retarding of the airflow by turbulent mixing is transmitted to the entire thickness of the lower layer. These processes together determine the wind and temperature profiles in the considered 100-m layer of the atmosphere.

Our objective was development of a method for approximate computation of the frequency of occurrence of a combination of temperature and wind velocity at heights of 50 and 100 m on the basis of surface data. This was accomplished, for the most part, using data from the 300-m mast at Obninsk, kindly put at our disposition by the Institute of Applied Geophysics. These data made it possible to check the basic formulas, and what is most important, were used for direct checking of factual data on the computed frequency of occurrence of a combination of temperature and wind velocity at a height of 100 m. In our investigations we used observations of air temperature and wind velocity at heights of 8, 48.6 and 96.8 m for eight times of observation, each three hr (0100, 0400, 0700, 1000, 1300, 1600, 1900 and 2200 hr) separately for the winter (January-February and December 1962 and 1963) and the summer (June-August 1962-1964) seasons. Unfortunately, the observations were made sporadically and therefore during the mentioned years and months there were only 390 observations, of which 148 were in winter and 242 in summer.

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*Numbers given in margin indicate pagination in original foreign text.

The high mast is situated in slightly dissected terrain, typical for the middle zone of the European part of the USSR. The grounds surrounding the high mast, with an area of about 14 hectares, is a trapezoidal quadrilateral oriented with its bases from SSE to NNW and surrounded by a fence about 2.5 m high. /63 Adjoining from the SE is a mixed forest with trees 10-15 m high. The forest gives way to the E and the NE boundary of the grounds is already at a distance of 300-400 m from the forest. Fields extend to the NW and SW.

The grounds themselves constitute a meadow which is mowed in summer. At its NW corner and on the S boundary there are two small groups of bushes. The mast is situated in the NW part of the grounds; 200 m to the E of the mast there is a meteorological observation station. Directly under the mast there are two small one-story buildings. In addition, in different directions from the mast there are other small structures.

Data obtained from the high mast of the Institute of Applied Geophysics have been used in making a series of studies, which have been published, on the turbulence and meteorological regimes and for study of processes of atmospheric diffusion and the propagation of impurities.

Problems of the wind profiles and the characteristics of the turbulent regime in the lower 300-m layer of the atmosphere have been considered directly.

For an investigation of the relationships between the turbulent and meteorological regimes it is necessary to have a classification (at least approximate) of the stationary state of the lower layer of the atmosphere using a simple quantitative stratification criterion.

As such a criterion of stratification of the lower part of the boundary layer the authors of (ref. 1) used the values of the ratio of the temperature difference at the 2- and 100-m levels and the difference of wind velocity at the 100- and 9-m levels. In addition, four groups of the state of stratification (higher-level classification) were defined for instable and neutral states of the lower layer (inversions were not considered).

Sources (refs. 14 and 15) give a definition of the state of stratification on the basis of surface observations, in which the principal parameters are wind velocity at the level of the vane and the characteristics of the radiation balance: insolation or solar altitude and the state of the cloud cover (surface classification). In a comparison of the higher-level classification and the surface classification in (ref. 1) it was clarified that the higher-level classification makes it possible to break down the state of stratification more finely than the surface classification. The surface classification does not take into account the influence of the underlying surface (roughness z_0) and this is a shortcoming of the classification. With the parameter z_0 taken into account the surface classification would make it possible to determine the state of stratification more precisely.

In (ref. 6) the wind and temperature profiles were analyzed using the Obukhov-Monin method in which the wind and temperature profiles are determined unambiguously by the turbulent heat flux (q_0), turbulent shearing stress (τ_0) and the roughness parameter (z_0). The lower part of the boundary layer was analyzed using the Monin-Kazanskiy method, which is based on the characteristics of the surface layer: q_0, τ_0, z_0 and these are supplemented by Coriolis force $l=2\omega\sin\varphi$.

As the dimensionless parameter characterizing the influence of stratification on the turbulent regime in the lower part of the boundary layer in this case we use

$$\mu = \frac{L}{L_1},$$

where $L = -\frac{v_*^3}{\varkappa \frac{g}{T_0} \frac{q_0}{c_p \rho}}$ is the height of the dynamic sublayer (here $\varkappa$ is the Kármán constant, v_* is dynamic velocity, $L_1 = \frac{\varkappa v_*}{l}$ is the height of the dynamic layer. /64

In the analysis of the wind and temperature profiles L_1 and μ are determined empirically. In the mentioned studies the wind and temperature profiles were considered with different temperature stratifications, first in the surface layer (8-9 m) and then in the lower part of the boundary layer.

Analysis of the wind velocity and temperature profiles in the surface layer revealed that despite some distortions of the flat underlying surface the surface layer in the neighborhood of the mast retains the character of a surface layer over a level surface, which makes it possible to use it for approximate determination of the characteristics of turbulence.

The Monin-Kazanskiy method for the lower part of the boundary layer, proposed in (ref. 6), could not be used as the basis for this study due to the complexity of its application. Therefore, in this study a simplified method was adopted for investigating the wind and temperature profiles in the 100-m layer for purposes of practical application.

For describing the distribution of wind velocity we checked the applicability of a simple power law in this layer and as a characteristic of stratification we considered the temperature gradients as a function of wind velocity at the level of the vane (8 m) and the extent of the lower cloud cover, that is, the adopted classification in its parameters was close to the surface classification.

Thus, this study gives a separate analysis of the distribution of temperature and wind velocity in the 100-m layer, their combination, and computations of the frequency of occurrence of a combination of temperature and wind velocity aloft on the basis of surface data and established relationships prevailing in the 100-m layer.

Temperature data at the levels 8, 48.6 and 96.8 m were used in determining the vertical temperature gradients (γ°/100 m) in the layers 8-48.6 m (50-m layer) and 8-96.8 m (100-m layer). Graphs (fig. 1) were constructed for determining the dependence of the vertical temperature gradient (γ) in the 50- and 100-m layers on wind velocity at the Earth's surface (at a height of 8 m). /65

The graph shows that negative temperature gradients in the 50- and 100-m layers in both winter and summer are observed for the most part when the wind velocity at the Earth's surface is from 0 to 3 m/sec, that is, the temperature inversions in the lower 100-m air layer usually are formed in those cases when there are weak wind velocities at the Earth's surface (0-3 m/sec). The formation

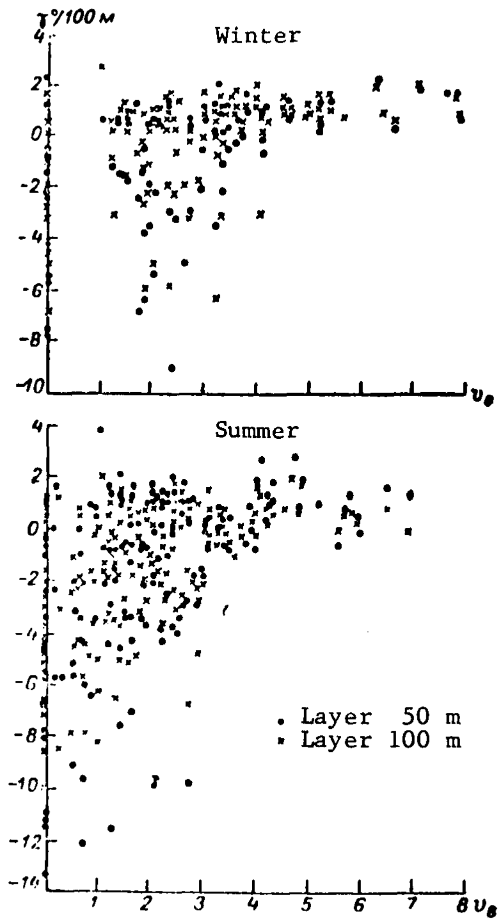


Figure 1. Dependence of vertical temperature gradient (γ°/100) in the 50- and 100-m layers on wind velocity at the Earth's surface (H=8 m).

of inversions when the wind velocity at the Earth's surface was more than 3 m/sec was noted only in individual cases.

The determined pattern made it possible to carry out investigations of the temperature regime separately for cases with wind velocity at the Earth's surface ≤3 m/sec and >3 m/sec.

Since cloud cover exerts a great influence on the character of the distribution of the principal meteorological elements in the lower layer of the atmosphere, the data were analyzed taking into account the extent of lower-level cloud cover.

All data were considered in dependence on the extent of the lower cloud cover--0-7 tenths (clear and semiclear sky) and 8-10 tenths (overcast sky).

Thus, investigation of the value of the vertical temperature gradient (γ) was made taking into account the following combinations of wind velocity (v) at the Earth's surface and the extent of the lower cloud cover:

Wind velocity (m/sec)	Lower cloud cover (tenths)
≤3	0-7
≤3	8-10
>3	0-7
>3	8-10

Table 1 gives the mean values of the vertical temperature gradients (γ) for observation times for the mentioned combinations.

The data in table 1 show that the values γ in both winter and summer differ substantially in dependence on the extent of the lower cloud cover, 0-7 or 0-8 tenths, when the wind velocity at the Earth's surface is ≤3 m/sec and have less significant differences in the case of a wind velocity >3 m/sec.

Despite individual "jumping" values γ at some times, caused by a small number of observations, the γ-values have a clearly expressed diurnal variation, particularly for weak wind velocities (0-3 m/sec) and a small cloud extent (0-7 tenths).

In winter, when the wind velocity at the Earth's surface is ≤3 m/sec and the lower cloud cover is 0-7 tenths the γ-values during the course of the day retain negative values in the 100-m layer, but in the 50-m layer at the time of the observations at 1300 hr γ has a positive value. The daily variations in the 50-m layer are 5° and in the 100-m layer--3.5°. In overcast weather the daily changes are considerably less and constitute about 2°, but the γ-values during a large part of the day have positive values. With a wind velocity >3 m/sec the daily γ-variation is expressed weaker, although it is noted that the γ-values increase in the daytime hr and even may attain superradiabatic values; this does not contradict the investigations of P. A. Vorontsov in (ref. 4). The daily variations in the case of a small extent /67
of the cloud cover are about 1°; in the case of a considerable cloud cover--several tenths of a degree.

TABLE 1. MEAN γ-VALUES FOR OBSERVATION TIMES IN 50- (γ_{50}) AND 100- (γ_{100}) LAYERS IN DEPENDENCE ON DIFFERENT COMBINATIONS OF WIND VELOCITY AND CLOUD COVER.

Hours	$v \leqslant 3$ m/sec Cloud cover						$v > 3$ m/sec Cloud cover					
	0–7			8–10			0–7			8–10		
	No. of cases	γ_{50}	γ_{100}	No. of cases	γ_{50}	γ_{100}	No. of cases	γ_{50}	γ_{100}	No. of cases	γ_{50}	γ_{100}
						Winter						
1	5	−3,4	−2,3	7	−0.2	0.1	7	0,6	0,7	4	1,0	1,0
4	4	−4,4	−3,6	4	−0.6	−0,1	2	0,2	−1,0	2	1,2	1,1
7	5	−4,4	−2,6	12	−0,3	0,6	3	1,2	1,3	3	1,3	1,1
10	6	−0,3	−1,0	2	0,3	0.5	1	1,5	1,6	—	—	—
13	5	0,6	−0,1	5	0,7	0,8	2	1,7	1,8	8	1,3	1,2
16	1	−1,4	−0.9	2	1,2	1.0	2	0.5	0,4	—	—	—
19	8	−2,4	0,9	8	0,4	0,3	3	0,9	0,9	7	1,1	1,1
22	6	−2,2	−0,5	3	0,3	0,1	—	—	—	3	1,1	1,3
						Summer						
1	32	−4,4	−3,4	2	−0,2	−0,9	1	−0,5	−1.0	1	−0,5	−0,1
4	24	−4,4	−3,6	—	—	—	1	−0,7	−0,2	3	−0,2	−0.2
7	25	0,3	−0,5	5	1,0	0,5	4	0.7	0,5	—	—	—
10	7	0,8	1,0	—	—		4	1,9	1,2	3	0,4	0,4
13	13	1,7	1,3	1	0,0	0,6	9	1,5	1,2	7	1,2	0,8
16	3	0,9	0,7	—	—	—	1	1,0	0,9	—	—	—
19	30	1,3	−0,5	3	0,0	0,0	6	0,1	0,2	—	—	—
22	27	−3,8	−2,6	4	−1,5	−0,7	—	—	—	—	—	—

Note: All commas in tables represent decimal points.

In summer the diurnal variation of γ is more clearly expressed. For a wind velocity ≤ 3 m/sec and a cloud cover of 0-7 tenths the negative values γ begin from 1900 hr and persist in the 100-m layer to 0700 hr, that is, the duration of persistence of inversions is about 12 hr. In the daytime hr the γ-values increase sharply and at 1300 hr attain superadiabatic values. In this case the daily variations are 6° in the 50-m layer and 5° in the 100-m layer.

With a wind velocity >3 m/sec the γ-values increase in the daytime hr to superadiabatic values and persist for approximately 6-7 hr.

Since the number of observations at individual times of observation of different groups was small, the determined mean γ-values for some observation periods are of low reliability. Therefore, in order to obtain more reliable characteristics of the temperature profile we computed the mean γ-values and their frequency of occurrence (table 2) for the day (regardless of cloud cover and wind velocity) and night (depending on cloud cover with a wind velocity ≤ 3 m/sec and independently of cloud cover when the wind velocity is >3 m/sec). The observations made at 1900, 2200, 0100, 0400 and 0700 hr in winter and at 2200, 0100 and 0400 hr in summer are considered "nighttime" and observations at 1000, 1300 and 1600 hr in both winter and summer are considered "daytime."

Analysis of the collected data on the vertical temperature gradients for daytime and nighttime revealed that in winter in the daytime (1000-1600 hr), despite the attenuated influx of solar energy and a negative radiation balance, the γ-values in the lower 100-m layer for the most part are positive and on the average are $0.6^{\circ}/100$ m. At nighttime, during clear and calm weather, winter radiation inversions are formed. With a wind velocity at the Earth's surface ≤ 3 m/sec and a small extent of lower cloud cover (0-7 tenths) the γ-values have maximum negative values and on the average attain $-3.2^{\circ}/100$ m in the 50-m layer and $-1.8^{\circ}/100$ m in the 100-m layer. The maximum negative γ-value is observed in the 50-m layer and is $-14.6^{\circ}/100$ m; in the 100-m layer it is $-6.7^{\circ}/100$ m. /68

On an overcast night with attenuated terrestrial radiation the development of inversions is less probable. In this case the γ-values are small and usually have positive values; the maximum frequency of occurrence is for the values 0.3-$0.5^{\circ}/100$ m when the wind velocity is ≤ 3 m/sec. When the wind velocity is >3 m/sec the maximum frequency of occurrence is for the values 0.7-$1.0^{\circ}/100$ m (the mean γ-value is $0.9^{\circ}/100$ m).

In summer during the daytime when there is strong turbulent mixing in the 50-m layer there are superadiabatic gradients; the maximum frequency of occurrence is for the values 1.1-$1.2^{\circ}/100$ m. The predominant gradients in the 100-m layer are 0.8-$1.0^{\circ}/100$ m.

At nighttime, as a result of cooling of the underlying surface and the surface air layers, when there are weak winds at the Earth's surface (≤ 3 m/sec), there are nighttime radiation inversions. The strongest inversions in this layer are developed in calm weather with a limited cloud cover. The γ-values in this case have the maximum negative values and on the average attain $-4^{\circ}/100$ m in the 50-m layer and $-3^{\circ}/100$ m in the 100-m layer, that is, more

TABLE 2. MEAN AND MOST FREQUENTLY REPEATING γ-VALUES FOR DAYTIME AND NIGHTTIME IN DEPENDENCE ON DIFFERENT COMBINATIONS OF WIND VELOCITY AND CLOUD COVER.

Time	Extent of lower cloud cover	v (m/sec)	Layer (m)	γ Means	γ Most frequently repeating
			Winter		
Daytime	Nondependent		8 50	0,6	From 0,6 - 1,2
			8 100		0,7 1,2
Nighttime	0 7	<3	8 -50	-3,2	—2,0 3,0
			8 100	—1,8	1.0 2,0
	8—10	<3	8 - 50	—0,2	0.3
			8 - 100		0,5
	Nondependent	>3	8 50	0,9	From 0,7 - 1,0
			8 - 100		
			Summer		
Daytime	Nondependent		8 - 50	1,2	From 1,1 - 1,2
			8 - 100	1,0	" 0,8 - 1,0
Nighttime	0—7	<3	8 - 50	—4,2	"-3,0 " -4,0
			8 - 100	—3,2	" 2,0 " -3,0
	8 10	<3	8—50	—0,8	"—0,6 " —1,0
			8 - 100		"—0,1 " -0,5
	Nondependent	>3	8—50	—0,3	"—0,1 " —0,5
			8 - 100		

significant than in the winter (the maximum negative γ-value observed was -19.0°/100 m in the 50-m layer and -10.0°/100 m in the 100-m layer).

It should be noted that of all the considered observations in the nighttime hr in summer the greatest number of cases occurred in calm weather with few clouds. This apparently can be attributed to the fact that the standard observations on the high mast were made for the most part when anticyclonic weather conditions prevailed.

In overcast weather when there was a low cloud cover of 8-10 tenths the inversions were weaker, the γ-values were considerably smaller and averaged about -0.8°/100 m.

In the case of a wind velocity at the Earth's surface >3 m/sec the inversions usually do not develop significantly, the state of the atmosphere in such cases is close to isothermal and the vertical temperature gradients are about -0.2 or -0.3°/100 m.

A logarithmic or power-law dependence frequently is used for computing the wind profile in the lower part of the boundary layer. The vertical distribution of wind velocity in the 100-m layer, both with an ordinary temperature decrease and in an inversion layer (temperature increase) can be expressed by a simple power law. Although a simple power law does not give such a good agreement with the true wind profiles as a generalized power law, it gives a good approximation for a wide range of heights and is considerably better for use in mathematical analyses.

In this paper computations of the wind profile were checked using the formula

$$v = v_1 \left(\frac{z}{z_1} \right)^m, \tag{1}$$

where v is wind velocity at the heights 50 and 100 m; v_1 is wind velocity at /69 the Earth's surface (at H=8 m); z is the heights 50 and 100 m; z_1 is the initial level (8 m); m is a coefficient dependent on the state of the atmosphere (vertical temperature gradient γ).

The dependence of m on γ in the range from -1.0° to $1.2^\circ/100$ m can be expressed, according to (refs. 2 and 4), through an equation of the form:

$$m = 0{,}190 - 0{,}085\,\gamma - 0{,}025\,\gamma^2. \tag{2}$$

The dependence of m on γ, obtained from a combination of data for the 300-m mast and a study by Vorontsov in (ref. 6), is represented graphically in figure 2.

On the graph 1 is the dependence of m on γ in inversions, taken from (ref. 5); 2 is the dependence of m on γ, computed as the mean value using data from the 300-m mast for the 50- and 100-m layers for 1900, 2200, 0100, 0400 and 0700 hr. The fields of data 1 and 2 coincide, which may be regarded as confirmation of empirical formula (1). These computations of the mean wind velocity in the daytime and in inversion layers for heights of 50- and 100-m using formula (1) revealed that the differences between the actual and computed velocities for the most part do not exceed ±0.6-0.8 m/sec.

In addition, as a characteristic of the vertical distribution of wind velocity during the day we computed the differences of wind velocity (Δv) in the 50- and 100-m layers for day and night (table 3).

As might be expected, the differences of wind velocities in the 50- and 100-m layers at nighttime are greater than during the daytime. Whereas in winter in weather with few clouds the nighttime differences exceed the daytime differences by approximately a factor of 2, in summer when the wind velocities at the Earth's surface are ≤3 m/sec they exceed the nighttime differences by approximately a factor of 4-5. The increase of the difference of wind velocity

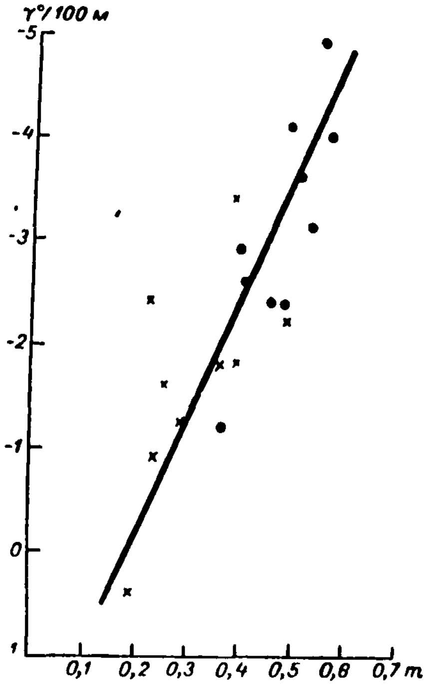


Figure 2. Dependence of m on $\gamma^{\circ}/100$ m. X, 1; •, 2.

TABLE 3. DIFFERENCES OF WIND VELOCITIES (Δv) in 50- AND 100-M LAYERS (NUMBER OF CASES GIVEN IN PARENTHESES.)

v (m/sec)	Daytime		Nighttime			
			Cloud cover (tenths)			
			0–7		8 10	
	Δv_{50}	Δv_{100}	Δv_{50}	Δv_{100}	Δv_{50}	Δv_{100}
			Winter			
<3	1,2 (22)	1,8 (23)	1,4 (16)	2,6 (17)	1,0 (29)	1,4 (30)
>3	0,9 (15)	1,7 (15)	2,4 (14)	4,1 (14)	1,4 (18)	2,1 (18)
			Summer			
<3	0,6 (26)	0,7 (27)	2,5 (55)	4,0 (58)	2,1 (5)	3,0 (6)
>3	1,0 (24)	1,6 (24)	1,9 (4)	4,5 (4)	2,0 (2)	3,6 (2)

at nighttime can be attributed to the predominance in the lower 100-m layer of radiation inversions (especially strongly expressed in summer) in which it is well known that there is a rapid increase of wind velocity with height.

The dependence of the difference of wind velocity (Δv) in the 50- and 100-m layers on wind velocity at the Earth's surface (v_8) at nighttime in summer is shown in figure 3.

The graph shows that the differences (Δv) in the 50- and 100-m layers have a maximum scatter when there is a zero wind velocity at the Earth's surface. In the 50-m layer the scatter of points is less than in the 100-m layer and for the most part varies in the range 2 m/sec (1-3 m/sec). The mean differences Δv in the 50-m layer remain almost constant with an increase of wind velocity at the Earth's surface. /70

In the 100-m layer the scatter of points varies from 1 to 7 m/sec; however, the mean differences Δv increase with an increase of wind velocity at the Earth's surface.

The data in table 3 show that in winter in daytime the determined differences (Δv) when the wind velocities at the Earth's surface are ≤ 3 m/sec and >3 m/sec are almost identical, whereas at nighttime when the winds are >3 m/sec the differences are considerably greater than when ≤ 3 m/sec, especially in weather with few clouds. During daytime in summer the differences Δv are small, which is due to intensified turbulent mixing.

Now we proceed to analysis of the combination of temperature and wind velocity in the 100-m layer. Computations of the frequency of occurrence of a combination of temperature and wind velocity were made using surface data (8 m) and at a height of 100 m for 5° temperature gradations and for wind velocity gradations of 1 m/sec for day and night in winter and summer (table 4). As indicated above, the observations for the most part apply to anticyclonic weather conditions.

The data in table 4 show that in winter the values of the combination of temperature and wind velocity at the Earth's surface both during the day and at night are grouped in the temperature range from -25° to $+5^\circ$ and the wind velocity range from 0 to 8 m/sec. The maximum frequency of occurrence of the combination for all temperature gradations falls at a wind velocity of 2 m/sec. The differences of the frequency of occurrence of the combination between day and night in winter are limited to the fact that at nighttime the highest percentage of occurrence of the combination by wind velocity gradations falls at lower temperatures (-10, -15°) than in daytime (-5, -10°).

The distribution of the combination at a height of 100 m in winter is grouped in the same temperature range as at the Earth's surface, but the wind velocity range increases to 10-11 m/sec. /71

The maximum frequency of occurrence of the combination in daytime and nighttime falls at temperatures -10, -15° and wind velocities 2 and 6 m/sec.

In summer in daytime at the Earth's surface the values of the combination of temperature and wind velocity are grouped in the temperature range 10-30° and wind velocity range 0-7 m/sec, with a maximum frequency of occurrence for the temperature gradations 15-20° and wind velocity gradations 2-3 m/sec.

Summer, nighttime

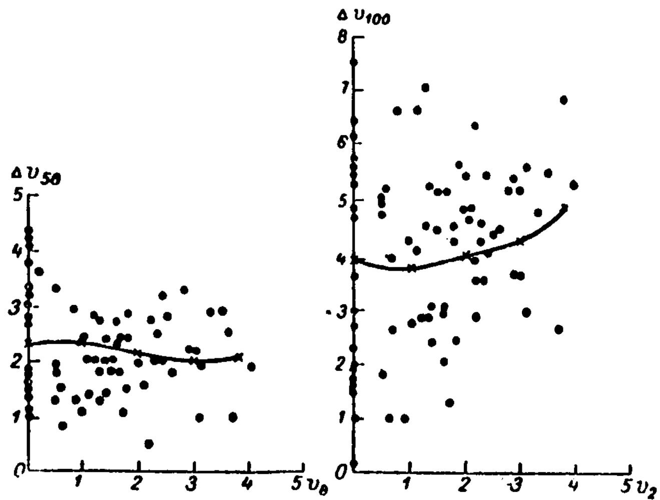


Figure 3. Dependence of differences of wind velocities in the 50- and 100-m layers on wind velocity at the Earth's surface (H=8 m).

At nighttime the values of the combination are distributed in the range of lower temperatures (0-25°) and lesser wind velocities (0-4 m/sec) with a maximum frequency of occurrence for the temperature gradations 10-15° and wind velocity gradations 0-2 m/sec.

The distribution of the combination at a height of 100 m in summer during the daytime is the same with respect to temperature as at the Earth's surface, but the wind velocity range increases somewhat (1-10 m/sec). At nighttime the distribution of the combination is displaced in comparison with the surface combination in the direction of higher temperatures (5-30°) and very sharply in the direction of higher wind velocities (0-11 m/sec), which can be attributed to the high frequency of occurrence of inversions in this period.

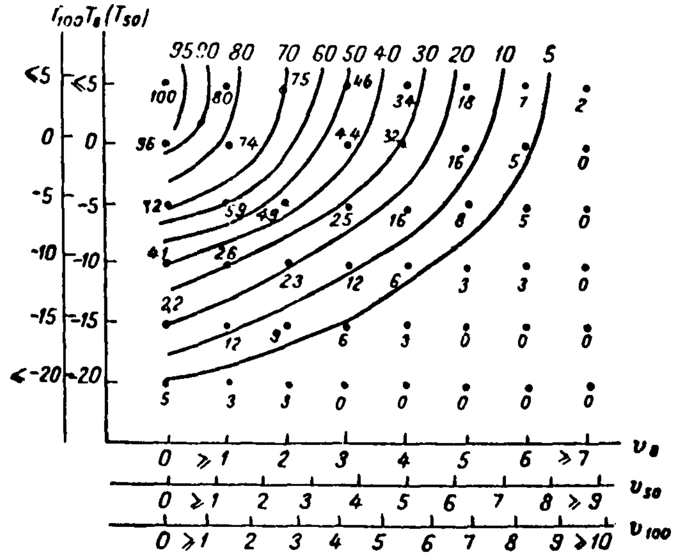
Data on the frequency of occurrence of the combination were used in computing the probability of occurrence of a combination of temperature (equal to or less than certain limits) and wind velocity (equal to and less than certain limits in summer and equal to and greater than certain limits in winter) at heights of 8 and 100 m and corresponding nomograms were constructed (fig. 4). In this work we used the method of representation of combinations in the form of projections of the integral surfaces of distribution, proposed in (ref. 9).

Construction of nomograms to some degree makes it possible to exclude random errors. Using the nomograms it is possible to determine the frequency of occurrence or probability of occurrence of any gradation of a particular combination, including gradations broken down further than those used in our computations. However, the greatest importance of the surface nomograms in this work is that is becomes possible to use them for computing the probability of occurrence of a combination at the heights 50 and 100 m.

TABLE 4. FREQUENCY OF OCCURRENCE (%) OF COMBINATION OF TEMPERATURE AND WIND VELOCITY AT HEIGHTS OF 8 AND 100 M.

v (m/sec)	Temperature, In winter: From 24,9 To –20,0	From –19,9 To –15,0	From 14.9 To –10,0	From –9.9 To –5,0	From –4.9 To 0,0	From 0,1 To 5,0	Temperature, In summer: 0.1–5,0	5,1–10,0	10,1–15,0	15.1–20.0	20,1–25,0	25,1–30,0
DAYTIME												
Height 8 m												
0	2	8	5	5	—	—	—	—	—	2	—	—
1	—	3	—	—	—	2	—	—	2	10	4	—
2	3	—	8	13	3	2	—	—	—	19	4	4
3	—	3	3	3	3	—	—	—	—	10	7	4
4	—	3	—	5	8	—	—	—	4	6	4	2
5	—	—	—	3	8	—	—	—	4	—	2	2
6	—	—	3	2	—	—	—	—	2	4	2	—
7	—	—	—	—	—	2	—	—	2	—	—	—
Height 100 m												
1	—	2	8	3	—	—	—	—	—	6	—	—
2	2	—	10	3	—	—	—	—	2	17	4	1
3	—	3	3	3	3	—	—	—	—	11	4	—
4	—	—	—	3	8	2	—	—	—	2	9	2
5	—	5	—	5	—	—	—	—	2	6	9	4
6	—	3	5	3	3	—	—	—	—	4	—	—
7	—	2	—	—	10	—	—		2	—	—	—
8	—	—	3	3	3	—	—	—	5	2	2	—
9	—	—	—	—	—	—	—	—	—	—	2	—
10	—	—	—	—	2	—	—	—	4	—	—	—
NIGHTTIME												
Height 8 m												
0	2	2	1	—	—	—	—	6	19	11	—	—
1	—	—	3	1	—	—	1	1	—	12	5	—
2	4	2	16	12	8	—	1	6	16	6	1	—
3	1	3	7	4	4	2	—	1	4	2	3	—
4	—	—	9	1	2	1	—	1	1	3	—	—
5	—	—	3	—	7	—	—	—	—		—	—
6	—	1	—	—	—	1	—	—	—	—	—	—
7	—	—	—	—	1	—	—	—	—	—	—	—
8	—	—	—	1	—	1	—	—	—	—	—	—
Height 100 m												
0	—	—	—	—	—	—	—	—	1		—	—
1	—	1	1	—		—	—	—	1	—	—	—
2	—	3	7	5	1	—	—	—	3	6	3	—
3	1	4	4	—	3	—	—	1	2	2	—	—
4	—	—	5	3	3	—	—	1	1	7	2	1
5	—	2	6	6	1	—	—	1	2	8	1	—
6	—	1	7	3	5	—	—	1	11	12	2	—
7	—	1	3	2	3	—	—	1	5	6	3	—
8	1	—	3	1	5	—	—	1	6	2	3	—
9	—	1	—	—	2	—	—	—	2	1	—	—
10	—	—	2	—	2	1	—	—	—	—	—	—
11	—	—	—	—	1	—	—	—	—	1	—	—

Winter, daytime (1000, 1300 1600 hr)



Summer, daytime (1000, 1300, 1600 hr)

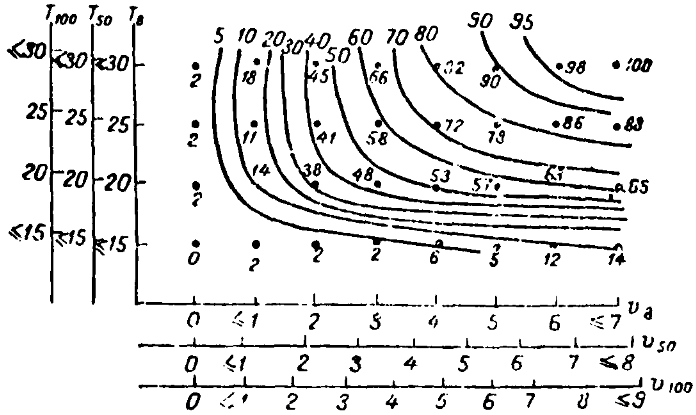


Figure 4. Nomograms of the probability of occurrence (projections of integral distribution surfaces) of a combination of temperature and wind velocity at the Earth's surface and at heights of 8, 50 and 100 m.

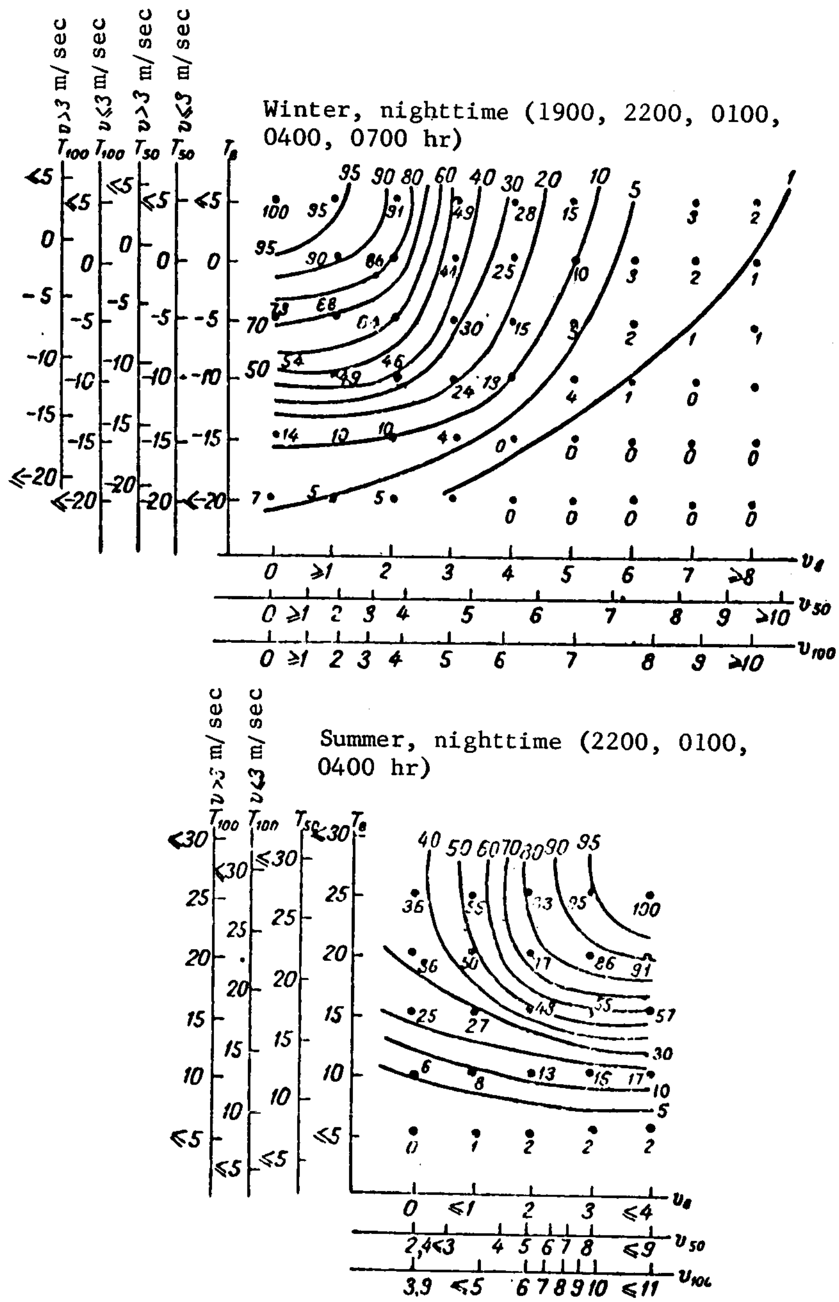


Figure 4. Concluded.

The nomograms were used in compiling tables of the probability of occurrence of a combination of temperature and wind velocity at the Earth's surface and at heights of 100 m (Appendix).

Using the nomograms of the probability of occurrence of a combination of temperature and wind velocity at the Earth's surface (H=8 m) and established dependences of the wind and temperature profiles, we made experimental computations of the frequency of occurrence of the combination at heights of 50 and 100 m and the results were compared with observational data. For making these computations we added to the nomograms of the probability of occurrence of a surface combination specially computed temperature and wind velocity scales for heights of 50 and 100 m. For nighttime we computed two temperature scales for wind velocities at the Earth's surface ≤3 m/sec and >3 m/sec. The temperature change in the layer was taken from the mean vertical temperature gradients with an accuracy to 0.5° (table 5). /75

At nighttime, with a wind velocity at the Earth's surface ≤3 m/sec, the influence of winter cloud cover was taken into account by computing the mean arithmetical γ-values for weather with a limited cloud cover (0-7 tenths) and overcast conditions (8-10 tenths) because the number of analyzed observations for these categories was approximately the same (28 cases of cloud cover in the 0-7-tenths category and 34 cases in the 8-10- tenths category). With respect to the long-term data on the frequency of occurrence of cloud cover for the particular region, the probability of an overcast sky at nighttime in winter is 75 percent; the probability of a limited cloud cover was 25 percent.

TABLE 5. γ-VALUES AND CORRECTIONS TO SURFACE TEMPERATURE (Δt) FOR COMPUTING TEMPERATURE AND WIND VELOCITY SCALES.

Time	Wind velocity (m/sec)	Layer (m)	γ	Correction to T_8
		Winter		
Daytime	Nondependent	8–50 8–100	0,6	0,0 –0,5
Nighttime	<3	8–50 8–100	–1,4 –0,8	+0,5 +1,0
	>3	8–50 8–100	0,9	–0,5 –1,0
		Summer		
Daytime	Nondependent	8–50 8–100	1,2 1,0	–0,5 –1,0
Nighttime	<3	8–50 8–100	–4,0 –3,0	+2,0 +3,0
	>3	8–50 8–100	–0,3	0,0 +0,5

Therefore, in computing the frequency of occurrence of the combination aloft on the basis of long-term surface data when constructing the temperature and wind velocity scales the γ-value must be used taking into account the frequency of occurrence of cloud cover in the 0-7- and 8-10-tenths categories.

At nighttime in summer the scales were computed using γ for weather with a limited cloud cover (0-7 tenths) because the overwhelming number of observations was made under these conditions (83 cases in the 0-7 category and 6 cases in the 8-10 category).

According to long-term data, the probability of an overcast sky is about 50 percent, that is, the number of nights with an overcast sky and a limited cloud cover is approximately identical. Therefore, in computing the frequency of occurrence of the combination on the basis of long-term data it is possible /76 to use the mean arithmetical γ-values for cloud cover in the 0-7- and 8-10-tenths category.

The wind velocity scales for heights of 50 and 100 m were computed using a simple power law. We used formula (1) in computing wind velocities at heights of 50 and 100 m (table 6) for different γ-values (table 5) for a given wind velocity at the Earth's surface and then constructed graphs of wind velocity aloft as a function of wind velocity at the Earth's surface. The wind velocities aloft for the 50- and 100-m levels were read from the graphs. The break in the scales for a wind velocity at the Earth's surface of 3 m/sec in the nighttime hr was graphically interpolated. In addition, for nighttime in summer the computation of the wind velocity scale was somewhat complicated because the use

TABLE 6. WIND VELOCITIES AT HEIGHTS OF 50- AND 100-M AS FUNCTION OF WIND VELOCITY AT THE EARTH'S SURFACE (v_8) FOR DIFFERENT γ-VALUES.

γ°/100 м	v_8 (m/sec)						
	1	2	3	4	5	10	15
Height 50 m							
1,2	1,1	2,2	3,3	4,4	5,5	11,0	16,4
0,9	1,2	2,4	3,5	4,7	5,9	11,8	17,7
0,6	1,3	2,5	3,7	5,0	6,3	12,6	19,0
−0,3	1,5	2,9	4,4	5,9	7,4	14,7	22,0
−1,4	1,8	3,6	5,4	7,1	9,0	—	—
−4,0	2,6	5,3	8,0	10,6	13,4	—	—
Height 100 m							
1,0	1,2	2,4	3,6	4,9	6,1	12,2	18,3
0,9	1,3	2,6	3,8	5,1	6,3	12,6	18,9
0,6	1,4	2,7	4,1	5,5	6,9	13,8	20,7
−0,3	1,7	3,4	5,2	6,8	8,5	17,0	25,5
−0,8	1,8	3,7	5,5	7,4	9,2	—	—
−3,0	3,2	6,5	9,4	12,9	16,2	—	—

TABLE 7. PROBABILITY OF OCCURRENCE OF A COMBINATION OF TEMPERATURE AND WIND VELOCITY AT HEIGHTS OF 8 AND 100 M (OBS - OBSERVED, COM - COMPUTED).

Winter

v (m/sec)	≤ 20°			≤ −15°			≤ −10°			≤ −5°			≤ 0°			≤ 5°		
	H_{8_Φ}	H_{100}		H_{8_Φ}	H_{100}		H_{8_Φ}	H_{100}		H_{8_Φ}	H_{100}		H_{8_Φ}	H_{100}		H_{8_Φ}	H_{100}	
		Φ	p		Φ	p		Φ	p		Φ	p		Φ	p		Φ	p
Daytime (1000, 1300 and 1600 hr)																		
> 0	5	—	—	21	—	—	40	—	—	72	—	—	93	—	—	100	—	—
> 1	3	2	4	12	17	18	30	46	38	59	69	67	78	98	86	82	100	88
> 2	2	2	3	8	15	13	22	37	28	44	57	75	65	83	74	70	87	77
> 3	0	0	0	5	13	8	12	28	22	28	45	44	44	70	61	50	74	66
> 4	0	0	0	3	10	6	7	20	15	16	37	32	30	56	47	34	60	55
> 5	0	0	0	0	8	4	3	18	10	8	29	22	15	45	37	18	47	40
> 6	0	0	0	0	5	2	1	11	6	4	20	13	5	34	25	7	36	27
> 7	0	0	0	0	2	0	0	5	3	0	12	8	0	22	14	2	23	17
> 8		0	0		0	0		3	2		5	4		11	7	0	11	8
> 9		0	0		0	0		0	0		0	1		2	2		2	4
> 10		0	0		0	0		0	0		0	0		2	0		2	2
Nighttime (1900, 2200, 0100, 0400 and 0700 hr)																		
> 0	7	—	—	14	—	—	50	—	—	75	—	—	95	—	—	100	—	—
> 1	5	2	4	11	15	10	50	52	42	70	74	68	91	99	91	96	100	97
> 2	3	2	4	10	14	9	43	50	40	60	71	66	80	96	88	87	98	95
> 3	1	2	4	6	11	8	24	41	40	31	58	62	43	81	83	49	82	93
> 4	0	1	2	2	9	8	10	33	30	17	48	52	23	68	70	28	70	80
> 5	0	1	1	0	6	5	4	26	20	6	39	30	10	56	44	15	59	49
> 6	0	1	0	0	4	4	1	19	14	3	27	20	4	41	27	5	44	29
> 7	0	1	0	0	3	1	0	10	4	1	16	7	2	25	11	3	28	14
> 8	0	1	0	0	2	0	0	6	1	1	8	2	1	15	3	2	19	4
> 9		0	0		1	0		3	0	0	3	1	0	8	1	0	10	3
> 10		0	0		0	0		2	0		2	0		5	1		6	2
> 11		0			0			0			0			1	0		1	0

(Φ = obs = observed; p = com = computed).

TABLE 7. CONCLUDED.

Summer

v (m/sec)	< 5°			< 10°			< 15°			< 20°			< 25°			< 30°		
	H_{8_ϕ}	H_{100}		H_{8_ϕ}	H_{100}		H_{8_ϕ}	H_{100}		H_{8_ϕ}	H_{100}		H_{3_ϕ}	H_{100}		H_{8_ϕ}	H_{100}	
		φ	p		φ	p		φ	p		φ	p		φ	p		φ	p
Daytime (1000, 1300 and 1600 hr)																		
0	—	—	—		—	—	0		—	2	—	—	2	—	—	2	—	—
< 1	—	—	—	—	—	—	2	0	2	13	6	10	17	6	13	18	6	13
< 2	—	—	—	—	—	—	2	2	3	33	22	27	42	29	34	45	30	34
< 3	—	—	—	—	—	—	4	2	6	44	33	43	58	43	52	66	45	55
< 4	—	—	—	—	—	—	6	2	7	52	38	50	72	55	64	82	62	72
< 5	—	—	—	—	—	—	10	4	10	57	45	56	78	70	75	90	74	83
< 6	—	—	—	—	—	—	12	4	15	62	50	63	85	76	80	97	83	90
< 7	—	—	—	—	—	—	14	6	18	65	54	66	88	80	86	100	88	95
< 8	—	—	—	—	—	—	—	11	20	—	59	70	—	84	90		94	98
< 9	—	—	—	—	—	—	—	11	20	—	61	71	—	89	92		96	100
<10	—	—	—	—	—	—	—	15	—	—	65	—	—	92	—		100	
Nighttime (2200, 0100 and 0400 hr)																		
0	0	—	0	6	0		23	1	—	32	1	—	38	1	0	—	1	—
< 1	1	—	0	8	0	0	28	2	2	50	2	7	55	2	9	—	2	9
< 2	2	—	0	13	0	0	45	5	5	77	10	13	82	11	18	—	11	18
< 3	2	—	0	16	1	1	55	8	8	86	18	20	95	19	27	—	19	27
< 4	2		0	17	2	2	57	10	10	91	25	27	100	30	36	—	30	36
< 5	—	—	0	—	3	3	—	16	17	—	36	40		43	54	—	46	56
< 6		—	0	—	4	4	—	25	22	—	61	60		68	77	—	69	80
< 7		—	0	—	5	4	—	31	25	—	72	65		83	83	—	81	86
< 8	—		0	—	6	5	—	38	28	—	81	70		95	87	—	96	90
< 9	—	—	0	—	6	5	—	40	30	—	84	71		97	91		99	93
<11	—	—	0	—	6	14	—	40	52	—	84	90		97	99	—	100	—

APPENDIX

PROBABILITY OF OCCURRENCE (%) OF A COMBINATION OF TEMPERATURE AND WIND VELOCITY AT HEIGHTS OF 8 AND 100 M.

Winter

v (m/sec)	Daytime (1000, 1300 and 1600 hr)						Nighttime (1900, 2200, 0100, 0400 and 0700 hr)					
	≤ −20°	≤ −15°	< −10	≤ −5°	<0°	≤5°	< −20°	≤ −15°	< −10°	< −5°	<0°	≤5°
Height 8 m												
>0	5	21	40	72	93	100	7	14	50	75	95	100
≥1	3	12	30	59	78	82	5	11	50	70	91	96
>2	2	8	22	44	65	70	3	10	43	60	80	87
>3	0	5	12	28	44	50	1	6	24	31	43	49
>4	0	3	7	16	30	34	0	2	10	17	23	28
>5	0	0	3	8	15	18	0	0	4	6	10	15
>6	0	0	1	4	5	7	0	0	1	3	4	5
>7	0	0	0	0	0	2	0	0	0	1	2	3
>8							0	0	0	1	1	2
Height 100 m												
> 1	2	17	46	69	98	100	2	15	52	74	99	100
> 2	2	15	37	57	83	87	2	14	50	71	96	98
> 3	0	13	28	45	70	74	2	11	41	58	81	82
> 4	0	10	20	37	56	60	1	9	33	48	68	70
> 5	0	8	18	29	45	47	1	6	26	39	56	59
> 6	0	5	11	20	34	36	1	4	19	27	41	44
> 7	0	2	5	12	22	23	1	3	10	16	25	28
> 8	0	0	3	5	11	11	0	2	6	8	15	19
> 9	0	0	0	0	2	2	0	1	3	3	8	10
>10	0	0	0	0	2	2	0	0	2	2	5	6
>11								0	0	0	1	1

Summer

v (m/sec)	Daytime (1000, 1300 and 1600 hr)				Nighttime (2200, 0100 and 0400 hr)					
	≤15°	≤20°	≤25°	≤30°	≤5°	≤10°	≤15°	≤20°	≤25°	≤30°
Height 8 m										
0	0	2	2	2	0	6	23	32	38	—
<1	2	13	17	18	1	8	28	50	55	—
<2	2	33	42	45	2	13	45	75	82	—
<3	4	44	58	66	2	16	55	86	95	—
<4	6	52	72	82	2	17	57	91	100	—
<5	10	57	78	90						
<6	12	62	85	97						
<7	14	65	88	100						
Height 100 m										
0	—	—	—	—		0	1	1	1	1
<1	0	6	6	6		0	2	2	2	2
<2	2	22	29	30		0	5	10	11	11
<3	2	33	43	45		1	8	18	19	19
<4	2	38	55	62		2	10	25	30	30
<5	4	45	70	74		3	16	36	43	46
<6	4	50	76	83		4	25	61	68	69
<7	6	54	80	88		5	31	72	83	84
<8	11	59	84	94		6	38	81	95	96
<9	11	61	89	96		6	40	84	97	99
<10	15	65	92	100		6	40	84	97	99
<11						6	40	85	99	100

of a simple power law in the case of strong inversions with extremely weak wind velocities at the Earth's surface (from 0 to 1 m/sec) leads to a large error. For this reason computations of the scale in the segment 0-1 m/sec were made using the corresponding differences of wind velocity obtained using observations on the high mast at Obninsk for the mentioned surface velocities.

Since in strong inversions there usually is a rapid increase of wind velocity with height, the differences of wind velocity in the 50- and 100-m layers are particularly large when the wind velocities at the Earth's surface have zero values and on the average at nighttime in summer are 2.4 m/sec in the 50-m layer and 3.9 m/sec in the 100-m layer (fig. 3), that is, in cases of very weak wind velocities at the Earth's surface the mean wind velocities aloft in inversions are quite considerable. Therefore, in the case of strong inversions (summer, nighttime) the wind velocity scales in the segment 0-1 m/sec at the Earth's surface were computed taking into account the differences (Δv), but above 1 m/sec--using a simple power law.

The probability of occurrence of a combination of temperature and wind velocity for a height of 100 m was read from the nomogram for 8 m using scales obtained by the mentioned method. The results of probability of occurrence of a combination obtained by this method for a height of 100 m and observed data for the combination are given in table 7. Since at nighttime in summer the mean velocity at a height of 100 m was 3.9 m/sec when the wind velocity at a height 8 m was zero, the probability of occurrence of the combination for velocities 1-3 m/sec was linearly extrapolated from the probability of occurrence of wind velocities from 4 to 0 m/sec. /79

The data in table 7 show that the values of the probability of occurrence of a combination of temperature and wind velocity at a height of 100 m, obtained by the proposed method, are close to the observed values and the maximum differences between them for the most part do not exceed 10-12 percent.

Thus, having initial surface data for temperature and wind velocity, and using the nomograms of the probability of occurrence of a combination, we may determine the frequency of occurrence for a combination of temperature and wind velocity at heights of 50 and 100 m, using the appropriate scales for this purpose.

Conclusions

1. For an approximate computation of the frequency of occurrence of a temperature and wind velocity combination at heights of 50 and 100 m based on surface data, it is possible to use a simplified model of the distribution of the characteristics of the turbulent regime in the 100-m layer using nomograms of the probability of occurrence of the combination (projections of the integral surfaces of distribution).

2. Atmospheric stratification was determined using the following parameters: the value of the vertical temperature gradient (γ), wind velocity at the Earth's surface (H=8 m) and the extent of the cloud cover at different times of day. It was possible to define four groups of state for different combinations

of wind velocity at the Earth's surface (≤3 m/sec and >3 m/sec) and cloud cover in the 0-7- and 8-10-tenths categories.

3. In computing the distribution of wind velocity in the 100-m layer it is possible to use a simple power law of the form $v=v_1\left(\frac{z}{z_1}\right)^m$ for daytime and nighttime conditions and for daytime conditions in summer. A change of wind velocity in the 100-m layer when there are strong inversions (summer, nighttime) and very weak wind velocities at the Earth's surface (0-1 m/sec) does not fit into the power-law dependence and therefore in order to obtain sufficiently correct results it is necessary that in these cases the mean wind velocity be computed using the wind velocity differences (Δv).

4. In order to determine the temperature changes in the layer and to compute the exponent m in formula (1) it is sufficient to use for the vertical temperature gradients (γ°/100 m) the mean values in daytime, regardless of cloud cover and wind velocity, but at nighttime they should be used differentially, with wind velocity and the frequency of occurrence of a cloud cover taken into account.

5. The probability of occurrence of a combination of temperature and wind velocity at a height of 100 m, obtained by computations, is close to the observed values; the differences between them for the most part do not exceed 10-12 percent. The proposed method therefore can be used for approximate computations in the solution of some practical problems.

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